ÉCOLE DOCTORALE
SCIENCES DE LA TERRE ET DE L'ENVIRONNEMENT
ET PHYSIQUE DE L'UNIVERS, PARIS

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Subject title: Inversion of seismic waveforms for petrological structure models and their validation via geodynamic-seismic simulation

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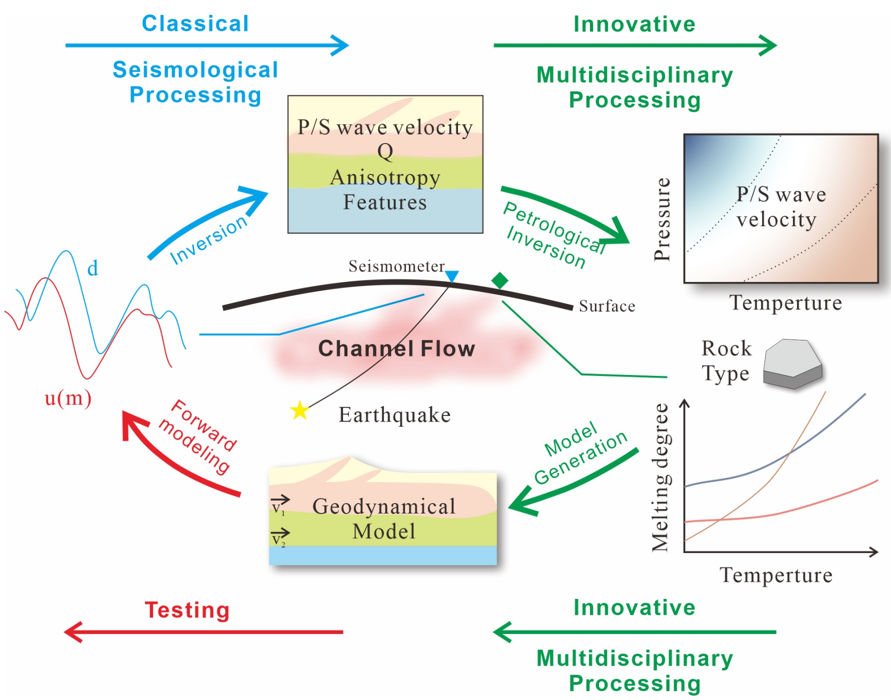
Host lab/ Team: **IPGP- Seismology/Marine Geosciences – UMR7154**

Financing: Doctoral contract preferably with teaching assignment

Graphic Abstract



Aim

The project aims to develop a multi-stage inversion process to estimate anisotropic seismic parameters in order to infer petrological, and dynamical characteristics of subsurface structures. Ultimately, we aim to create robust geodynamical models that link seismic data with petrological and rheological parameters. This method will be applied to study the composition and structure of the channel flow in the Tibetan Plateau, ultimately evaluating the feasibility of the channel flow model in the Plateau's evolution and its extent of influence.

Background

Channel flow model is one of the most popular models to interpret the growth of the high plateau and the associated thickening of the crust. This model invokes horizontal viscous flow in the mid-lower crust, transporting large volumes of crustal rocks into the eastern, southeastern and northeastern Tibet and thus inflating the crust there; this mechanism does not require significant shortening of the upper crust (*1*).

The viscous flow was observed by several geophysical profiles in the most part of the Tibet. In southern Tibet, numerous studies have explored this region using geophysical methods. For instance, receiver function results have revealed a low-velocity zone in the mid-crust (*2*). (*3*) identified a weak lower – middle crust by the INDEPTH profile through seismic anisotropy of Rayleigh and Love wave propagation. MT profiles have identified a high-conductivity layer in mid-crust (*4*, *5*), and geothermal measurements show elevated heat values in Southern Tibet (*6*). Together, these findings support the possibility of widespread mid-crustal partial melting in southern Tibet (*7*). In addition, two crustal low-velocity channels beneath SE Tibet are observed by joint inversion of Rayleigh wave dispersion and receiver functions (*8*). The low-velocity layer can also be seen in eastern and northeastern Tibet using receiver function method. (*9*, *10*).

However, the crustal flow model remains controversial. Tomography profiles indicated the low-velocity high-conductivity layer are locally distributed and have poor connectivity, which makes it impossible to generate large-scale flow (*11*). Also, the lack of sub-horizontal zones of reflectivity within the crystalline seismic in the reflection profiles and the existence of some faults that cut through the crust to the Moho do not support the channel flow (*12*, *13*). Although there are a lot of studies suggest the existence of channel flow in the eastern part of Tibet, there is a long debate about whether a southward flow exist in the southern Tibet. In addition, previous studies also provided some evidences for co-existing channel flow and pure-shear crustal thickening (*14*). Some studies suggested that pure shear mechanism alone can account for the Cenozoic crustal thickening in the eastern Tibet (*15*).

We can conclude that the key questions of channel flow are whether a flow layer can exist in the deep crust and the scale of its influence.

The fundamental requirements for channel flow are the presence of a low-viscosity layer and a pressure gradient (*16*). Thus, it is crucial to identified the composition of the low-velocity, high-conductivity layer.

Whether it contains aqueous fluids or melt and the percentage of melt in the layer are still unknown (*5*). The ratio of partial melting can be estimated by the mineral composition of metamorphic rocks (*17*) or electrical conductivity in MT profiles (*18*, *19*). However, the results of surface sampling in petrology studies could not accurately represent the results of deep crust and the results obtained by different estimation methods are different.

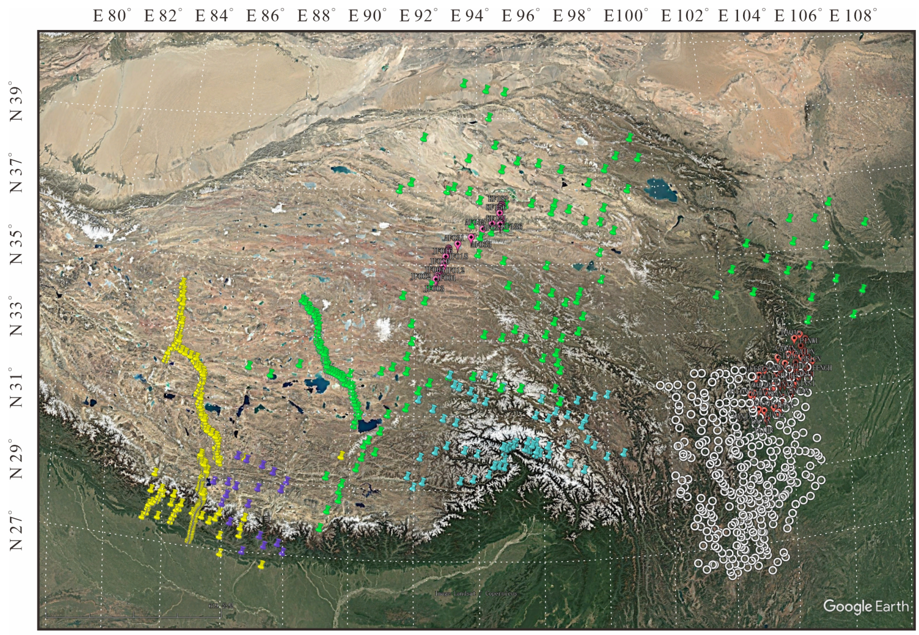
Leucogranites in the Himalayan orogenic belt are considered key products of mid-crustal partial melting. Some studies suggest that the decompression and exhumation of the High Himalayan Crystalline series may be the primary mechanism for this melting (*20*). Channel flow is regarded as one of the possible mechanisms of exhumation. The protolith of leucogranites is directly relates to the composition of crustal flow and can help determine the existence of channel flow. Firstly, different protoliths exhibit varying degrees of melting under different temperature and pressure conditions, leading to differing responses in geodynamic process. Secondly, in the channel flow model, the flow transports partially molten material from the Asian crust southward, suggesting that the protolith of leucogranites may originate from Asian crustal material (*21*). However, petrological methods struggle to distinguish the relationship between the Asian and Indian crusts, making it difficult to directly ascertain the origin of the leucogranites (*22*) and thereby hindering further validation of the crustal flow model.

Geophysical profiling can reveal the current structure and state of the deep crust, providing information on seismic wave velocities, anisotropy, and other properties at depth. However, the resolution of traditional geophysical methods limits the detailed imaging of deep structures, and insights into the composition and properties of deep materials remain constrained. Petrological studies can help us understand regional rock composition but lack the capacity to assess large-scale, deep conditions or the current state at depth. Therefore, although geophysical approaches may face challenges such as problem-solving limitations and error propagation, formal estimation of these parameters is essential.

This project takes the next step by using seismic inversion results to infer geological and petrological properties such as temperature, composition, water content, and crystal orientation at depth. This petrological tomography will integrate new geochemical data, leveraging tools like Perple_X (*23*), Litmod2D (*24*) and recent studies (e.g. *25*) to build a more accurate Jacobian matrix that relates partial derivatives of seismic parameters to those of petrological parameters. A key goal is to achieve a 3D map of rock types based on seismic and geochemical data.

Data

We plan to utilize publicly available broadband seismometer data from the Tibetan Plateau, including datasets from IRIS and GFZ, specifically from the INDEPTH, Hi-climb, Himnt, Namche Barwa Tibet and Longmen Shan projects, as well as data from the ChuanXi project from China Earthquake Administrator (*26*). These datasets provide comprehensive coverage of southern Tibet, eastern Tibet, and northeastern Tibet, effectively encompassing the locations of low-velocity and high-conductivity layers identified in previous studies, as well as the primary sources and pathways of channel flow. This extensive data will provide sufficient information to support our investigation into the existence and extent of channel flow in the region.



	Project	Time
IRIS		
Yellow	Hi-climb	2002-2005
Purple	Himnt	2001-2002
Green	INDEPTH 2-4	1994;1997-1999;2007-2009
Blue	Namche Barwa Tibet	2003-2004
GFZ		
Pink	INDEPTH 4	2007-2008
Red	Longmenshan	2012-2013
Other		
White	Chuanxi	2006–2009

figure1: Station distribution and data acquisition time of different open data sets

Methodology

1. Seismic full waveform inversion: We will first complete isotropic full waveform inversion before transitioning to anisotropic parameters and Q inversion, using box-tomography techniques (e.g. *27*, *28*). Despite anticipated difficulties with resolution, this will provide the seismic parameters necessary for the next stages.

2. Petrological tomography: We will invert the seismic parameters to derive geological and petrological properties using Perple_X (*23*), potentially refining this approach with recent geochemical data. We will ensure that the mapping of seismic parameters to petrological models is rigorous and accurate. The ambition here is to create a 3D rock map.

3. Geodynamical modelling: After developing petrological models, we will engage in geodynamical modeling, aiming to simulate tectonic processes in both 2D and 3D. This process will be based on underworld program which is a Python API (Application Programming Interface) and provides functionality for the modelling of geodynamics processes (*29*). These results will help to understand the effect of melting ratio on crustal deformation and explain the possible influence of channel flow on the growth and evolution of the Tibet. This stage will include trial-and-error modeling, refining these models to match seismic and topographic data.

4. Synthetic Waveform Generation and Scenario Testing: Using the geodynamical models, we will propagate synthetic seismic waves and test different scenarios to understand how various geological processes influence seismic data. At this stage, we will incorporate machine learning techniques to identify key data attributes that maximize the ability to distinguish between different geodynamical scenarios.

Calendar

1.2025/09-2025/12

- Conduct a comprehensive literature review
- Collect data and finish pre-processing

2.2026/01-2026/06

- Complete isotropic full waveform inversion
- Learning box-tomography techniques to get anisotropic parameters and complete Q inversion

3.2026/07-2026/12

- Finish box-tomography
- Perform petrological tomography

4.2027/01-2027/06

- Perform geodynamic modeling based on the tomography result
- Compare the synthesic data with the real data

5.2027/07-2027/12

- Discuss the problems of channel flow in combination with the results and literature
- Write an article and compose the PhD thesis

6.2028/01-2028/08

- Publish the article
- Submit the thesis and complete the project

Risk management

Every single step in this project alone is publishable.

Potential candidate

Zizhao Yuan (Sun Yat-sen University) has worked on the seismic data acquisition and waveform inversion for isotropic structures of the area of interest, as well as geochemical data analysis of the region. She is willing to continue working on the topic using the joint methods we propose in this PhD project.

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